Structural, Spectroscopic and Biological Aspects of O, N- Donor Schiff Base Ligand and its Cr(III), Co(II), Ni(II) and Cu(II) Complexes Synthesized through Green Chemical Approach

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Abstract: The monofunctional bidentate Schiff base ligand (*o*-vanillin) *p*-chloroaniline and its four new complexes of chromium(III), cobalt(II), nickel(II) and copper(II) have been synthesized by classical thermal and microwave-irradiated techniques. All the new derivatives have been characterized by elemental analysis, molecular weight determinations, molar conductance measurements, UV-Vis, IR and NMR spectral studies. The IR spectral data suggest the involvement of phenolic oxygen after deprotonation and azomethine nitrogen in coordination to the central metal ion. The growth inhibiting potential of the ligands and complexes has been assessed against a variety of fungal and bacterial strains.

Keywords: Bidentate Schiff base, Microwave-irradiated techniques, Green Chemical Approach

Introduction

The growing interest in Schiff base compounds is basically because of their raised biological activity and also they make possible development of novel materials with unique properties¹. Many applications of microwaves, as an efficient heating source for organic reactions, have been reported in the literature². Solvent free reaction have played strategic role in methodologies of organic as well as inorganic synthesis^{3,4}. Microwave heating has proved to be very useful tool to carry out certain organic transformations which not only excludes the use of hazardous non-eco friendly solvents but also enhances the reaction rates greatly. The main advantage of microwave assisted organic synthesis is the shorter reaction time using only small amount of energy. The concept of green chemistry is enshrined the prevention of waste, the use of safe, environmentally benign solvent where possible and use on renewable

feed stocks⁵. Schiff base have often been used as chelating ligands in the field of coordination chemistry and their metal complexes are of great interest for many years⁶. It is known that the existence of metal ions bonded to biologically active compounds may enhance their activities^{7,8}. The transition metal Schiff base complexes are applicable in areas such as bioinorganic, electrochemistry, environmental chemistry, metallic deactivators and separation technique⁹.

Experimental

All the reagents were dried and distilled before use *o*-vanillin and *p*-chloroaniline were purchased from Hi-media. Cupric acetate, cobalt acetate and nickel chloride were purchased from E.Merck. Chromium chloride was purchased from Thomas Baker.

Preparation of ligand

In microwave assisted synthesis the ligand was prepared by the condensation of respective aldehyde and amine in 1:1 molar ratio using a beaker through a conventional microwave oven by taking few mL solvent (ethanol), respectively. The reaction was completed in a short period of 2 minutes. The solution when cooled gave orange needle shaped crystals. These are washed in ethanol and dried over anhydrous CaCl_2 .

For comparison purpose, the above ligand was also synthesized by the thermal method, where instead of few drops of alcohol the starting material of the ligand was dissolved in 30ml of alcohol and the content was refluxed for 1.5 hours. The solution was cooled to room temperature to obtain the orange needle shaped crystals.

Preparation of the complexes

The complexes were also prepared by two different types. In microwave assisted synthesis, the complexes were prepared by irradiating the reaction mixture of metal salts (ethanol and double distilled water) and respective ligand in 1:2 molar ratios in benzene. The reactions were completed in 5 - 8 minutes. On cooling, the coloured complex precipitated out, which was filtered by suction, washed several times with ethanol and finally ether and dried over anhydrous CaCl_2 .

These complexes were also prepared by the thermal method where instead of 5 - 8 minutes reaction was completed in 3 to 4.5 hours and yield of the products was also less than that obtained by the microwave assisted synthesis. The purity of the compounds was checked by TLC. A comparison between thermal and microwave method is given in Table 1.

Table 1. Comparison between conventional and microwave methods of synthesis

Compounds	Yield, %		Solvent, mL		Time, min	
	Thermal	Microwave	Thermal	Microwave	Thermal	Microwave
(<i>o</i> -VPClH)	83	85	60	4	1.5	2
[Cr (<i>o</i> -VPCl) ₂ .Cl.H ₂ O]	73	81	50	6	3	5
[Ni (<i>o</i> -VPCl) ₂ .2H ₂ O]	77	82	45	6	3.5	4
[Co (<i>o</i> -VPCl) ₂ .2H ₂ O]	74	82	45	5	3.5	4
[Cu (<i>o</i> -VPCl) ₂]	73	89	50	5	5	7

Physical measurements and analytical data

Microanalyses of carbon, hydrogen and nitrogen of the complexes were carried on a Heraeus Carlo Erba 1108 elemental analyzer. Metals content were analyzed gravimetrically. IR spectra were recorded on a Perkin-Elmer infrared spectrophotometer in the range 4000–400 cm^{-1} .

Electronic spectra of the complexes were recorded on a Helios alpha. ^1H NMR spectrum of the ligand was recorded on a Bruker Avance 400 MHz. Molar conductances were measured at room temperature in DMSO using a dip type cell electrode. The molecular weights were determined by the Rast Camphor method.

Anti-microbial studies

Anti-bacterial studies

The antibacterial activity was evaluated by the paper disc method. The nutrient agar medium (peptone, beef extract, NaCl and agar - agar) and 5 mm diameter paper discs of Whatman No. 1 were used. The compounds were dissolved in DMSO in 500 and 1000 ppm concentration. The filter paper discs were soaked in different solutions of the compounds, dried and then placed in the petriplates previously seeded with the test organisms *E. coli*, *S. aureus*. The petriplates were stored in an incubator at $28 \pm 2^\circ\text{C}$ for 24 hours¹⁰.

Anti-fungal studies

Antifungal activities of the ligand and its complexes have been evaluated against two pathogenic fungi, *Aspergillus nigre* and *Fusarium oxysporum* by the agar plate technique. The potato dextrose agar (PDA) medium was prepared in the lab to maintain the fungal growth. Solutions of the test compounds in DMSO at 100 and 200 ppm concentrations were prepared and then were mixed with the medium. The medium was poured into petriplates and the spores of fungi were placed on the medium. These petriplates were wrapped in the polythene bags containing a few drops of the alcohol and were placed in an incubator at $25 \pm 2^\circ\text{C}$. The activity was determined after 96 hours of incubation at room temperature 25°C ¹¹.

Results and Discussion

In continuation of our research interest in microwave-assisted synthesis¹²⁻¹³ and the development of novel synthetic methodology¹⁴⁻²⁰, herein Schiff base ligand (*o*-vanilidene *p*-chloroaniline) was prepared by the conventional microwave and thermal reaction of *o*-vanillin and *p*-chloroaniline according to Figure 1.

Figure 1

The metal chelates in the present investigations were prepared according to the equation:

Physical properties

The resulting complexes are air stable, coloured solids. The observed molar conductance (7.8 to $10.4 \text{ ohm}^{-1} \text{ cm}^2 \text{ mol}^{-1}$) of all the complexes in 10^{-3} M dimethyl sulfoxide solutions suggests the non-electrolytic²¹ nature of these complexes. The analytical results (thermal & microwave method) of ligand and its complexes are presented in Table 2 & 3.

Table 2. Physical and analytical data of the ligands and its complexes synthesized by thermal heating

Compounds	M. P. °C	Mol.wt. Found (Calcd.).	Colour	Found (Calcd.), %				
				C	H	N	M	Cl
(<i>o</i> -VPClH)	110	253 (261.5)	Orange	63.91 (64.24)	4.47 (4.59)	5.25 (5.35)	—	13.39 (13.57)
[Cr (<i>o</i> -VPCl) ₂ .Cl.H ₂ O]	150	609.5 (626.5)	Brown	53.04 (53.63)	3.49 (3.83)	4.34 (4.47)	8.12 (8.30)	16.33 (16.99)
[Ni (<i>o</i> -VPCl) ₂ .2H ₂ O]	>360	610.86 (615.93)	Cherry Colour	54.13 (54.55)	4.03 (4.22)	4.11 (4.54)	9.24 (9.57)	11.40 (11.53)
[Co (<i>o</i> -VPCl) ₂ .2H ₂ O]	275	603 (615.5)	Light Brown	54.37 (54.59)	4.10 (4.22)	4.19 (4.55)	9.23 (9.50)	11.22 (11.52)
[Cu (<i>o</i> -VPCl) ₂]	240	589 (584.65)	Dark Green	57.00 (57.47)	3.31 (3.76)	4.57 (4.78)	11.00 (10.89)	12.00 (12.14)

Table 3. Physical and analytical data of the ligand & its complexes synthesized by microwave method

Compounds	M. P. °C	Mol.wt. Found (Calcd.)	Colour	Found (Calcd.), %				
				C	H	N	M	Cl
(<i>o</i> -VPClH)	110	255 (261.5)	Orange	64.00 (64.24)	4.53 (4.59)	5.31 (5.35)	—	13.39 (13.57)
[Cr (<i>o</i> -VPCl) ₂ .Cl.H ₂ O]	150	619.5 (626.5)	Brown	53.49 (53.63)	3.58 (3.83)	4.41 (4.47)	8.02 (8.30)	16.43 (16.99)
[Ni (<i>o</i> -VPCl) ₂ .2H ₂ O]	>360	611.86 (615.93)	Cherry Colour	54.00 (54.55)	4.13 (4.22)	4.27 (4.54)	9.32 (9.57)	11.00 (11.53)
[Co (<i>o</i> -VPCl) ₂ .2H ₂ O]	275	607 (615.5)	Light Brown	54.68 (54.59)	4.17 (4.22)	4.22 (4.55)	9.23 (9.50)	11.38 (11.52)
[Cu (<i>o</i> -VPCl) ₂]	240	580 (584.65)	Dark Green	57.02 (57.47)	3.42 (3.76)	4.63 (4.78)	11.01 (10.89)	11.98 (12.14)

Infrared spectra

The important IR spectral bands of the ligand as well as complexes are presented in Table 4. The IR spectra of the metal complexes show significant changes compared to the ligand. In the IR spectrum of the Schiff base ligand, a sharp band observed at 1616 cm^{-1} is assigned to the $\nu(\text{C}=\text{N})$ made of azomethine group²². This shifts to lower frequency by $4\text{--}6 \text{ cm}^{-1}$ in all the complexes, suggesting the coordination of the azomethine nitrogen to the metal centers. This is further substantiated by the presence of a new band at $491\text{--}476 \text{ cm}^{-1}$ assignable to $\nu(\text{M-N})$ ²³. The characteristic phenolic $\nu(\text{O-H})$ mode due to the presence of a hydroxyl group at ortho position in the ligand was observed at 3414 cm^{-1} . A band at 1298 cm^{-1} due to $\nu(\text{C-O})$ phenolic was observed in the ligand. The disappearance of the phenolic $\nu(\text{O-H})$ band in the complexes under study suggests the co-ordination by the phenolic oxygen after

deprotonation to the metal ion. This is further supported by the shifting of the $\nu(\text{C-O})$ phenolic to higher wave numbers in all the metal complexes. The complexes also showed medium intensity bands in the region $580\text{--}585\text{ cm}^{-1}$, which can be attributed to the respectively $\nu(\text{M-O})$ vibrations. The presence of lattice water molecules in the complexes is revealed by the appearance of a broad band at 3500 cm^{-1} due to $\nu(\text{O-H})$ ²⁴.

Table 4. IR spectral data of ligand and its metal complexes

Compounds	$\nu(\text{O-H})$ phenolic	$\nu(\text{C=N})$	$\nu(\text{C-O})$	$\nu(\text{M-O})$	$\nu(\text{O-H})$ coordinated water	$\nu(\text{M-N})$
(<i>o</i> -VPClH)	3414 br	1616s	1298m	-	-	-
[Cr (<i>o</i> -VPCl) ₂ .Cl.H ₂ O]	-	1610s	1304m	580w	3500br	480w
[Ni (<i>o</i> -VPCl) ₂ .2H ₂ O]	-	1611s	1301m	585w	3418br	481w
[Co (<i>o</i> -VPCl) ₂ .2H ₂ O]	-	1612s	1301m	584w	3412br	476w
[Cu (<i>o</i> -VPCl) ₂]	-	1610s	1302m	585w	-	491w

Electronic spectra

The electronic spectra of the complexes were measured in DMSO. Chromium complex exhibit three spin allowed transition 16880 cm^{-1} , 23094 cm^{-1} , 37230 cm^{-1} . This is consistent with octahedral geometry of Cr(III) complexes. The Co(II) complex showed three absorption bands around 10627 , 19325 , 23573 cm^{-1} , which assigned to the transition ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{2g}(\text{F})$, ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{A}_{2g}(\text{F})$ and ${}^4\text{T}_{1g}(\text{F}) \rightarrow {}^4\text{T}_{1g}(\text{P})$ respectively suggesting high spin octahedral geometry. The Ni(II) complex showed three bands at 10550 , 16750 and 25700 cm^{-1} respectively, exhibiting an octahedral geometry. The Cu(II) complex showed absorption bands in the region 15699 cm^{-1} and 24320 cm^{-1} respectively, in a tetragonal geometry.

¹H NMR spectra

The ¹H NMR spectrum of the ligand was recorded in CDCl₃-d₆. The proton signals at 7.246, 3.941, 6.902-7.406 and 8.622 δ ppm are due to the solvent, OCH₃ group, aromatic protons and azomethine ($-\text{CH}=\text{N}-$) proton, respectively. The signal at 13.391 δ ppm is due to phenolic ($-\text{OH}$) proton of vanillin²⁵. Thus, on the basis of the above studies the expected structures of the complexes may be represented as shown in Figure 2.

Figure 2. Structures of the complexes*Anti-microbial studies*

The ligand and its metal complexes were evaluated for their antimicrobial activity against two bacteria *Escherichia coli*, *Staphylococcus aureus* and two fungi, *Aspergillus niger* and *Fusarium oxysporum*. The results are summarized in Table 5&6. The results were compared with those of the standard drug streptomycin for bacteria and flucanazole for fungi.

Table 5. Antibacterial activity of the Schiff base ligand and their metal complexes, showing of diameter of inhibition zone

Compounds	<i>Eschirichia coli</i> , <i>Staphylococcus aureus</i> concentration			
	500 ppm	1000 ppm	500 ppm	1000 ppm
(<i>o</i> - VPClH)	14	15	14	16
[Cr (<i>o</i> -VPCl) ₂ .Cl.H ₂ O]	18	22	19	20
[Ni (<i>o</i> -VPCl) ₂ .2H ₂ O]	18	19	17	21
[Co (<i>o</i> -VPCl) ₂ .2H ₂ O]	17	21	17	21
[Cu (<i>o</i> -VPCl) ₂]	19	19	18	19
Streptomycin	23	25	22	25

Table 6. Antifungal activity of the Schiff base ligand and their metal complexes, showing of diameter of inhibition zone

Compounds	<i>Aspergillus nigre</i>		<i>Fusarium oxysporum</i>	
	100 ppm	200 ppm	100 ppm	200 ppm
(<i>o</i> - VPClH)	51	56	32	40
[Cr (<i>o</i> -VPCl) ₂ .Cl.H ₂ O]	68	70	53	63
[Ni (<i>o</i> -VPCl) ₂ .2H ₂ O]	71	78	55	60
[Co (<i>o</i> -VPCl) ₂ .2H ₂ O]	67	69	50	61
[Cu (<i>o</i> -VPCl) ₂]	78	80	52	57
Flucanazole	95	100	100	100

Conclusion

Microwave irradiation is an efficient and environmentally benign method to accomplish various inorganic syntheses to afford products in higher yields in shorter reaction periods. The metal complexes synthesized in 1:1 molar ratios with respective ligand were found to be tetracoordinated and hexacoordinated. The ligand behaves as a bifunctional tetradentate with the metal atom. Antimicrobial activity showed that the complexes are more active than the parent ligand.

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